J. Child Psychol. Psychiat. Vol. 30, No. 4, pp. 515-528, 1989
Printed in Great Britain.

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0021-9630/89 $3.00 + 0.00
Maxwell Pergamon Macmillan plc

Blood-Lead Levels and Children's Behaviour—Results from the Edinburgh Lead Study

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Abstract—The effect of blood-lead on children's behaviour was investigated in a sub-sample of 501 boys and girls aged 6–9 years from 18 primary schools within a defined area of central Edinburgh. Behaviour ratings of the children were made by teachers and parents using the Rutter behaviour scales. An extensive home interview with a parent was also carried out. Multiple regression analyses showed a significant relationship between log blood-lead and teachers' ratings on the total Rutter score and the aggressive/anti-social and hyperactive sub-scores, but not the neurotic sub-score when 30 possible confounding variables were taken into account. There was a dose–response relationship between blood-lead and behaviour ratings, with no evidence of a threshold.

Keywords: Blood-lead, behaviour scores, confounders, Rutter scores

Introduction

The Edinburgh Lead Study is a cross-sectional study of 501 pupils aged between 6 and 9 yrs of age from 18 local authority schools across the city of Edinburgh, Scotland. Raab, Fulton, Laxen and Thomson (1985) have already published details of the study design, and the results of ability and attainment tests for the 501 children for whom complete data were available have been reported by Fulton, Raab, Thomson, Laxen, Hunter and Hepburn (1987). The results show that there is a relationship between blood-lead levels and poor performance which retains significance after controlling for covariates. There is a dose–response relationship with no evidence of a threshold. Laxen, Lindsay, Fulton and Raab (1985) and Raab, Laxen and Fulton (1987) report

Accepted manuscript received 17 *October* 1988

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that lead in water and lead in dust are important sources of exposure. This paper reports on the influence of blood-lead levels on children's behaviour using data derived from teachers' observations of children's behaviour.

Within the lead research field there has been considerable interest in the relationship between body lead burden and deviant behaviour. Numerous studies have examined this relationship, with results sometimes being inconsistent and inconclusive. Some studies—for example Needleman, Gunnoe, Leviton, Reed, Peresie, Maher and Barnett (1979), Yule, Urbanowicz, Lansdown and Millar (1984) and Silva, Hughes, Williams and Faed (1988)—have suggested that there is a link between behaviour in children and lead levels. Other studies—for example Lansdown, Shepherd, Clayton, Delves, Graham and Turner (1974), Smith, Delves, Lansdown, Clayton and Graham (1983)—have failed to find evidence for such an association. Reviewing the existing evidence on this subject led Lansdown (1986) to conclude that

> ". . . the most recent epidemiological studies have failed to produce convincing, consistent evidence for an association between moderate levels of lead and behavioural patterns in general . . ." (p. 267)

This paper is intended to shed further illumination on a complex area where studies of the association between lead levels and cognitive ability, as well as behaviour, are subject to a number of methodological criticisms. Smith (1985) and Fergusson, Fergusson, Horwood and Kinzett (1988) include amongst these criticisms inadequate measurement of lead burden, problems of validity and reliability with tests, inadequate control of confounding variables etc. The design of the Edinburgh Lead Study was constructed with these criticims very much in mind.

The issue of validity and reliability of tests is relevant to the question of behaviour measures. Behaviour disturbance in children exposed to lead intoxication has been reported in the literature for some time (Byers & Lord, 1943; David, Clark & Voeller, 1972; David, Hoffman, Sverd & Clark, 1977; David, Hoffman, Clark, Grad & Sverd, 1983). The question of measuring disturbed behaviour has been addressed by researchers adopting either an ethnographic approach or a nomothetic approach. Harvey, Hamlin, Kumar and Delves (1984) made direct observations in controlled settings and, by means of video recording, subsequently analysed and cross-rated these observations. Such a technique is, of course, labour- and time-intensive, and so a trade-off has to be made in terms of quality of observations against time taken. Most researchers, as a consequence, adopt a nomothetic approach and use forced choice inventories or standardized behaviour rating scales for which normative data are available. In the lead research field, three such questionnaires have been widely used. These are the scale developed by Needleman *et al.* (1979), one developed by Conners (1969, 1973) and the Rutter (1967) scale. Rutter, Tizard and Whitmore (1970) report the use of this scale in its teachers' and parents' format.

The Needleman and Conners scales were developed in America. Apart from the Needleman *et al.* (1979) study itself, little is known of the properties of this scale since it was adapted from a longer scale specifically for use in a lead study. The Conners scales were developed for use in drug studies with children and, whilst Conners (1973) reports the sensitivity of the scales to drug-induced changes in behaviour, their use in normal contexts is limited. The Rutter scales were developed in the United Kingdom and have been used widely in clinical, educational and research contexts, with substantial data available on the robustness of the scales, as reported by Venables, Fletcher, Dalais, Schlusinger and Medrick (1983) and McGhee, Williams, Broadshaw, Chapel, Robins and Silva (1985) amongst others. In addition to the full-scale score, the scales yield separate sub-scores for aggressive/anti-social behaviour (A), hyperactive behaviour (H) and neurotic behaviour (N).

It was decided to use the Rutter scales in the present study for three reasons. The scales offered a valid and reliable measure of behaviour as rated by teachers and parents, thereby affording a potential for measuring pervasive behaviour disorders. The classic study by Mitchell and Shepherd (1966) reported the situational specificity of certain behaviours pointing to the role played by contexts in disturbed behaviour. Behaviours which are likely to be drug-induced, organically determined or resulting from neurological trauma are therefore more likely to be pervasive across time and contexts. The Rutter scales afforded the possibility of measuring such behaviour. A second reason for their choice was concerned with the time/quality trade-off. Here were a set of 26 behaviour descriptions each ranked on a 3-point scale which were detailed enough to provide factor scores but which could be completed by respondents relatively quickly. Lastly, the fact that the scales were developed and standardized on a United Kingdom population made their selection in this study consistent with the choice of the ability outcome measure argued by Fulton *et al.* (1987).

Method

As described elsewhere (Raab *et al.*, 1985), the children were recruited from primary schools in a defined area of central Edinburgh, selected to include the older houses in the city, some of which retain their original lead plumbing. The housing was not, however, of poor quality. For the families included in the study, 43% were in social class I or II, and 85% owned their own homes. In each school, the parents of all children in the 3rd and 4th years at school were asked for permission for their child to take part; 78% agreed, and a successful venous blood sample was obtained from 855 children and assayed for lead. At this stage, a sub-sample was selected for the main study which included the top quartile of the blood-lead distribution and a random sample (roughly 1 in 3) of the rest. These 501 children were tested in school by a trained psychologist who administered tests from the British Ability Scales (Elliott, Murray & Pearson, 1983) and tests of mental speed, and arranged for the child's teacher to complete the Rutter behaviour questionnaire for each child. Each child's family then received a visit from an interviewer who collected data on the home background, which included ability tests for one parent, usually the mother. Further stages of the study, which are not discussed here, included the assessment of the children's exposure to environmental lead and the collection of shed deciduous teeth. None of the research team who came in contact with the children had information on the children's lead levels. Great care was taken at all stages of the study to ensure the accuracy and reliability of all the data collected. Quality control procedures were implemented wherever possible and all data were coded and checked by two different people.

The interview data were used to construct scores for 30 potential confounding variables without reference to how these social and parental variables related to either blood-lead or the outcome measures. The confounders selected have been described by Fulton *et al.* (1987). Only 30 of the 33 covariates were used in the analyses described here. Two variables were not appropriate (time of day of tests, and year of schooling—the latter being implicitly included by controlling for teacher). The third covariate which was omitted was the score PARSCHL, which measured the parent's contact with the school.

This variable was found to give high scores for children whose performance on the ability and attainment tests was poor. Thus it was considered likely that its inclusion might lead to over adjustment.

The variables used were those which might be regarded as being related to a child's performance in ability, attainment tests and behaviour, as well as being possible determinants of lead exposure. The confounders were chosen from examination of relevant literature, as well as findings in other lead studies. Data were collected by interviewing one parent, normally the mother. These scores ranged from simple items, e.g. age and sex of child and parent's test scores, to more complex variables which combined related items from the questionnaire. The latter included, among others, a score for family structure, which was intended to measure the extent to which the child had been separated from parents, with greater weighting to recent changes of structure, and also a score for child's interest, which measured the cultural and educational activities which the child attended outside school hours.

The behaviour scores were used as dependent variables in regression analyses, with log blood-lead and the confounding variables as predictors. Two items which related to thumb-sucking and nail-biting were excluded from the calculation of the behaviour scores, since they might be a cause of increased lead uptake.

Results

The distribution of the behaviour scores, as reported by parents and teachers, were skew, with a large number of children scoring zero or a very low value, and only a few with higher scores. The distribution of teachers' scores for girls and boys separately are shown in Table 1.

Table 1. Total Rutter score—teachers

	0	1–2	3–5	6–9	9 +	Total
Boys	77	50	70	30	34	261
Girls	94	70	48	21	7	240
Total	171	120	118	51	41	501

"thumb-sucking" and "nail-biting" items are omitted from the scoring.

As has been indicated above, behaviour ratings were also made by parents, using the relevant Rutter scale. This scale is a form parallel to that used by teachers and allows comparisons to be made of children's behaviour in school and home settings. Table 2 shows the distributions for girls and boys separately.

Table 2. Total Rutter score—parents

	0	1–2	3–5	6–9	10–12	13 +	Total
Boys	10	33	57	79	34	34	247
Girls	13	38	87	60	18	20	236
Total	23	71	144	139	52	54	483

"thumb-sucking" and "nail-biting" items are omitted from the scoring.

Parents' scores tended to be higher than teachers'. Boys tended to score higher than girls on both scales, but the sex difference was more marked for teachers. Although there was a correlation (0.28) between the parents' and teachers' scores, there was also considerable disagreement. A cross-tabulation of these scores (Table 3) shows that there is a substantial number of children who scored high on the parents' scale but very low on the teachers' scale.

Table 3. Teacher score by parent score—total Rutter score

	Teacher					
Parent	0	1–2	3–5	6–9	9 +	Total
0	10	6	5	1	1	23
1–2	29	16	16	7	3	71
3–5	70	36	20	7	11	144
6–9	38	33	40	16	12	139
10–12	12	14	16	7	3	52
13 +	7	10	16	11	10	54
Total	166	115	113	49	40	483

"thumb-sucking" and "nail-biting" items are omitted from the scoring.

Rutter *et al.* (1970) reported on comparison of the scales, indicating that teachers' ratings are more likely to be reliable, given that they are better able to make relevant comparisons of each child with other children since the contexts in which they are making such observations contain a number of pupils demonstrating a range of behaviours, whereas parents are making their observations in the context of the home, with only limited points of comparison, if any. We shall examine the teachers' ratings first.

With the skew distributions mentioned above, ordinary regression results may be invalid, and a different technique developed by McCullagh (1980) known as polychotomous regression was used. This method is an extension of logistic regression to deal with a dependent variable of more than two ordered categories. The computations were carried out using the LOGIST procedure in SAS (1982). The initial analysis also controlled for all 30 potentially confounding variables. To allow for individual teachers differing in their use of the scales, "teacher" was included as a factor in the analysis. The coefficients of log blood-lead are given in Table 4. They correspond to the log odds ratio of being in a higher category when the blood-lead increases by a factor of 2.718. The coefficients are all positive, showing that a high blood level corresponds to a high behaviour score, although the coefficient for the neurotic scores is non-significant.

Other covariates

To obtain more insight into the role of influences other than lead on the behaviour scores, stepwise regression analyses were carried out. Log blood-lead and the factor

Table 4. Regression analyses of teachers' behaviour scores on log blood-lead, teachers and all covariates

Y-variable	Log blood-lead co-eff	p-value[a]	other influential covariates
Total score (range 0–24)	0.69	0.005	Sex, parents' matrices test, family structure
Aggressive/anti-social (range 0–11)	1.08	0.004	Sex, parents' matrices test, parent/child communication
Hyperactive (range 0–6)	0.66	0.02	Family structure, sex, parents' matrices test
Neurotic (range 0–6)	0.19	0.28	Gestation, parents' participation with child

[a]1-sided test

for teachers were entered first into the model, and the other covariates then allowed to enter in a stepwise manner. The univariate associations between the teachers' Rutter total score, blood-lead and the 21 of the 30 covariates which entered the stepwise regression are given in Table 5.

Table 5. Univariate correlations of blood-lead and Rutter (total) scores

Covariate	Label	Teachers' Rutter totsc	Log blood-lead
Child variables			
age	Age	0.11	−0.09
sex (m = 1; f = 2)	Sex	−0.19	−0.08
standardized height	Stheight	−0.14	−0.20
length of gestation	Gestat	0.04	0.05
birthweight	Brthwt	0.04	0.03
medical history score	Medhist	0.14	−0.08
days off school	Offsch	0.14	−0.05
Parent variables			
mother's qualifications	Mqualif	−0.19	−0.15
working mother	Workmum	0.00	−0.02
parent's health	Parhlth	0.13	0.01
parent's mental health (high score = problems)	Parment	0.13	0.01
No. of cigs smoked	Totcigs	0.19	0.08
parent's vocabulary	Pvoc	−0.14	−0.13
parent's matrices	Pmat	−0.23	−0.01
Family variables			
birth order	Brthord	−0.08	−0.06
family structure	Famhist	0.12	−0.04
parent/child communications	Parchom	−0.17	−0.05
child's interest	Childint	−0.18	−0.06
parent participation	Parpart	−0.11	−0.06
Household variables			
car/phone owner	Carphone	−0.13	−0.05
consumer goods owner	Consumer	−0.06	0.03
persons per room	Occuprat	0.11	0.05

The stepwise regressions for the teacher's scores (totsc, H, A, N) are shown in Tables 6–9, which also show how the log blood-lead coefficient is modified at each step. The most important variables influencing "totsc", H and A were similar, including "sex", "pmat", "famhist" and "totcigs". A different set, which included "gestat",

Table 6. Stepwise regression analyses for total score

Step No.	Extra variables entered	p-value for variable	Blood-lead coefficient	Direction
0	Teachers + log blood-lead	0.0008 (2-sided)	0.84	High lead bad
1	Sex	0.0000	0.77	Boys bad
2	Pmat	0.0002	0.76	Low pmat bad
3	Famhist	0.0001	0.77	High bad
4	Totcigs	0.0035	0.75	Cigs bad
5	Medhist	0.046	0.81	Ill bad
6	Gestat	0.070	0.75	Premature bad
7	Offsch	0.077	0.79	Offschool bad

Table 7. Stepwise regression analyses for hyperactivity score

Step No.	Extra variables entered	p-value for variable	Blood-lead coefficient	Direction
0	Teachers + log blood lead	0.008 (2-sided)	0.78	High lead bad
1	Pmat	0.0000	0.79	Low pmat bad
2	Totcigs	0.0002	0.77	Smoking bad
3	Famhist	0.0003	0.79	Disrupt bad
4	Sex	0.0002	0.78	Boys bad
5	Age	0.002	0.76	Younger bad
6	Medhist	0.016	0.87	Ill bad
7	Pvoc	0.028	0.87	Low pvoc bad
8	Stheight	0.97	0.73	Smaller bad

Table 8. Stepwise regression analyses for aggressive/anti-social score

Step No.	Extra variables entered	p-value for variable	Blood-lead coefficient	Direction
0	Teachers + log blood lead	0.0059 (2-sided)	1.00	More lead bad
1	Sex	0.0000	0.93	Boys bad
2	Pmat	0.0002	1.00	Low pmat bad
3	Famhist	0.0003	1.12	Disrupt bad
4	Totcigs	0.0059	1.07	Cigs bad
5	Parchom	0.007	1.09	Less comm. bad
6	Brthwt	0.097	1.08	Normal bad
7	Consumer	0.092	1.08	More video bad
8	Age	0.13	1.09	Older bad
9	Pvoc	0.15	1.11	High pvoc

Table 9. Stepwise regression analyses for anxiety/neurotic score

Step No.	Extra variables entered	p-value for variable	Blood-lead coefficient	Direction
0	Teachers + log blood lead	0.64 (2-sided)	0.14	
1	Gestat	0.016	0.06	Premature bad
2	Brthord	0.017	0.04	Oldest bad
3	Medhist	0.03	0.10	Ill bad
4	Parpart	0.056	0.09	Particip. bad
5	Parchom	0.099	0.10	No comm. bad

"brthord" and "famhist", influenced the N score. If "lead" had not been forced into these regressions, but had been allowed to compete for entry with the other covariates, it would have entered the regressions as follows:

totsc — at step 4 after "famhist"
H — at step 6 after "age"
A — at step 4 after "famhist"
N — would not have entered at the first 5 steps shown.

Interactions

For the three scores which showed a significant association with blood-lead (totsc, A and H), the data were analysed to examine interactions between the covariates for their influences on the scores. The interactions were tested by adding them, one at a time, into the models at the end of the stepwise procedures shown in Tables 6–8. The interactions tested for each outcome measure were those between "lead" and the other covariates in the model, and between "sex" and the other covariates. Because many interactions have been examined, the p-values of the results (shown in Table 10) should be interpreted with caution. Only two of the interactions with

Table 10. Interactions in regression analyses. Those interactions with nominal p-value (2-sided) < 0.1 are included

Outcome	Interactions Tested	Interactions Found	p-value	Direction
totsc	13	Sex × lead	0.09	Lead coefficient greater for boys
		Sex × pmat	0.04	pmat coefficient greater
H	15	Sex × famhist	0.03	Girls more influenced by famhist
A	17	Sex × consumer	0.04	Influence of covariate greater for boys
		totcigs	0.06	
		pmat	0.04	
		Lead × parchcom	0.04	Lead slope steeper when parchcom score is poor

"lead" approach significance. Of the six interactions with "sex", five are in the direction of a greater influence of a covariate for boys than for girls. This may well be a result of the different distribution of the scores for boys and girls (Table 1), which suggests that the scales may lack sensitivity in measuring girls' behaviour problems.

Analysis of parents' scores

As has been indicated above, agreement between the teachers' and parents' ratings was not uniform. Reasons for this have been mentioned earlier in this paper. It was possible, however, to make a partial analysis of the parents' ratings. Some items in the checklist were not completed by parents. Where this occurred, the values of the items were taken as zero. For one child there were five missing items. This subject was excluded from the "total" and "neurotic" scores, but was included in the other scores, since there were no missing items.

The full model was fitted for each of the four scores (total, aggressive/anti-social, neurotic, hyperactivity). Table 11 reports the results. The log blood-lead coefficient did not reach statistical significance for any of the scores. However, the direction was the same as that for the teachers' scores, and there was considerable overlap between the other influences on the corresponding parents' and teachers' scores.

Table 11. Regression analyses of parents' scores on log blood-lead and all covariates

	Log blood-lead		
Y-variable	co-eff	*p*-value + (1 sided)	other influential covariates
Total score	0.38	0.06	Sex, famhist, parment, totcigs, brthord, brthwt, childint, stheight
Aggressive/ anti-social	0.12	0.31	Sex, workmum, totcigs, carphone, childint, parchcom
Hyperactive	0.39	0.07	Sex, famhist, mqual, parhlth, totcigs, brthord, brthwt, stheight
Neurotic	0.33	0.08	Parment, offschl, stheight

The data were further analysed to examine deviant behaviour noted by both parent and teacher—i.e. a child would only score if both teacher and parent scores were high. To achieve this, the smaller of the child's two scores was taken. In this way it was believed that this would identify these children with true behavioural problems. The relationship of this score with lead might therefore be high. Table 12 reports the lead coefficients for the various scores. Although the *p*-values are less extreme, the results are similar to the results for the teachers' score. It could be argued therefore, that by adding in the information from the parents' score, rather than picking out the real problem children, noise is being added; hence, no further analyses were conducted. A more fruitful line of enquiry is to consider the dose–response relationship, and it is to this that we now turn.

Table 12. **Regression analyses of minimum of parents' and teachers' scores on log blood-lead, teachers and all covariates**

Y-variable	Log blood-lead Co-eff	Log blood-lead p-value + (1-sided)	other influential covariates
Total score	0.53	0.03	Sex, pmat, parment, totcigs, age, famhist, childint
Aggressive/ anti-social	0.95	0.02	Sex, famhist, pmat, occuprat, totcigs, parment, parchcom
Hyperactive	0.75	0.03	Totcigs, famhist, sex, mqual, medhist, pmat
Neurotic	0.23	0.27	Offschl, brthord, msoc

Dose–response relationship

The dose–response relationship for the full model was investigated using the model from Table 6 plus the "sex" by "pmat" interaction. The subjects ($n = 501$) were subdivided into 10 groups of approximately 50 children according to their blood-lead values. Table 13 shows the distribution of teachers' total scores by blood-lead group.

Table 13. **Teacher score for 10 groups by blood-lead—total Rutter score**

Blood-lead (μg/dl)	Teacher 0	1–2	3–5	6–9	9 +	Total
–6.9	18	13	11	3	2	47
7.0–8.2	27	8	10	4	3	52
8.3–9.4	15	14	11	7	2	49
9.5–10.8	13	16	10	5	7	51
10.9–11.6	21	7	16	5	1	50
11.7–12.6	25	11	13	3	2	54
12.7–14.1	14	11	11	6	6	48
14.2–15.7	12	15	8	8	6	49
15.8–18.6	14	14	17	6	2	53
18.7 +	12	11	11	4	10	48
Total	171	120	118	51	41	501

The polychotomous regression was then fitted with group as a factor and omitting lead. This gave a coefficient for each group which could then be expressed as a difference in log-odds for this group compared with the mean of the 501 children, adjusted for all the covariates in the model. These log-odds and their confidence intervals are plotted in Fig. 1, which also shows the regression line.

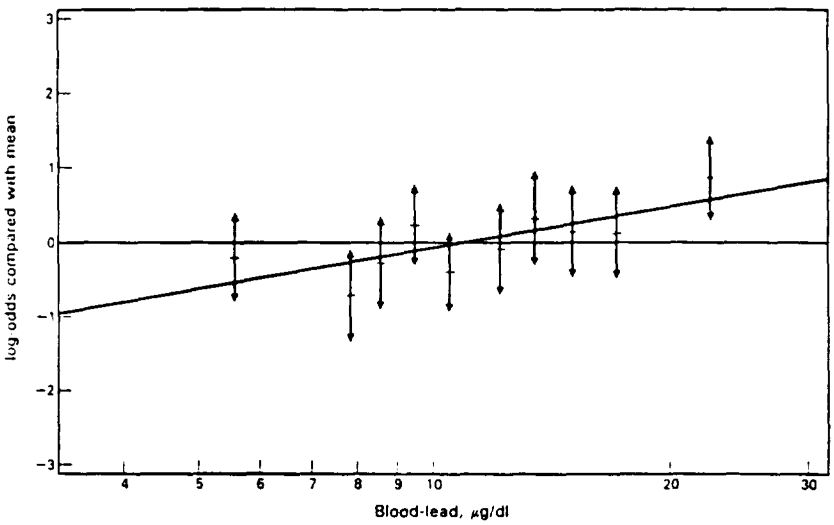

Fig. 1. Log-odds relative to population means of increased behaviour scores for groups ordered by log blood-lead.

The interpretation of the log-odds is most easily understood by an example. For the group with the highest blood lead, the log-odds of being in a higher category (relative to all the categories lower than it) are increased by the value 0.86 compared to those from an average child. Thus a child with given values of all the other covariates would have his or her odds of scoring 1 rather than 0 on the Rutter scale increased by a factor of exp (0.86) or 2.4. If the ratio of such children scoring 1 to those scoring 0 was 1:1 when their average blood-lead was the mean for the sample, then we would expect the ratio to be 2.4:1 if they were in the highest lead group. A similar relationship will hold for the ratio for those scoring 2 to those scoring less than 2, and so on for higher categories.

Figure 1 shows no evidence of any deviations from a linear relationship with blood-lead. The groups contain the same children as the equivalent British Ability Scores (BAS)—see Fulton *et al.* (1987). It is interesting to note that while the lowest lead group showed a deviation towards better performance than expected on BAS scores, this was not true for behaviour, where they behaved rather worse than would have been predicted from the regression line. If anything, it appears that the relationship is being driven by the highest group.

Similar plots were examined for the hyperactivity score (using the model above plus the "sex" by "famhist" interaction) and for the aggressive/anti-social score (using the model above plus "sex" by "consumer" and by "totcigs" and by "pmat" interactions). All these plots displayed a pattern similar to that for the total score.

Discussion

In 501 Edinburgh children with a mean blood-lead level value of 10.4 µg/dl there is a significant relationship between measures of deviant behaviour (total score, aggressive/anti-social score and hyperactive score) and blood-lead when confounding variables are taken into account. These measures of deviant behaviour are influenced by sex, mother's performance on a matrices test, history of family disruption and the total number of cigarettes smoked in the household. Furthermore, there is limited evidence of a lead by sex interaction, with a stronger effect for boys than girls. Studies such as Silva *et al.* (1988) have looked at the role of behaviour after controlling for ability. However, the causal mechanisms here are not clear, as the behaviour deficit may impair the child's learning ability. Hence, we have considered only the behaviour scores in this paper. A further report will consider all the outcome measures together to identify those factors which appear to be influenced by lead.

Analysis of the dose–response relationship suggests that the finding that deviant behaviour seems to be associated with body lead burden even at the relatively low levels of exposure reported by the Edinburgh Lead Study is not reported by these other studies, which used a different criterion measure for children's behaviour. For example, Smith *et al.* (1983) did not find such a relationship, although in many respects the two studies are similar in design, scope and major findings. The data from the Edinburgh study suggest the presence of a small tendency for blood-lead and deviant behaviour to be associated even after controlling for confounders. This relationship may reflect a causal association whereby low level lead exposure acts to influence deviant anti-social and hyperactive behaviour in pupils. Such an explanation is possible given the fact that at high dosages, lead is a known neurotoxin. Since the relationship was still evident after controlling for confounders, albeit at a modest level, this would further suggest the existence of an underlying causal connection. It may be argued that the underlying relationship between blood-lead and behaviour may well be stronger than is estimated here given the inevitable inaccuracy implicit in the measurement of behaviour traits. Fergusson and Horwood (1987a, b) offer a discussion of these issues.

Set against this view, however, is the recognition that lead and behaviour might well be associated by reverse causality, whereby variations in children's behaviour may lead to variations in body lead burden. The hyperactive, acting out aggressive child may well behave in ways which increase his/her lead levels, such as playing out of doors, being careless of hygiene etc. A feature of the Edinburgh study would suggest, however, that this is not the case. Reverse causation would be of less importance for water, which is an important source of exposure in Edinburgh (Raab *et al.*, 1987) than for other sources. The reverse causation hypothesis would be difficult to examine, however, except in an extensive longitudinal study on both lead and behaviour patterns. This is not to reject the hypothesis as far as the Edinburgh study is concerned, but to recognize the possibility that the association could be the result of some confounding variable for which no account was taken.

Despite this caveat, the results reported here add to the growing evidence that lead at low levels of exposure probably has a small but harmful effect on children's behaviour. It is difficult to assess this degree of risk. Whether or not it is minimal, it is an avoidable risk, and so all reasonable attempts to eliminate sources of environmental lead should be encouraged.

Acknowledgements—The authors wish to express their gratitude to all who assisted the project in data gathering and analysis. Thanks are given especially to the Education Department of Lothian Regional Council, who permitted access to schools, and to the children, their families and their teachers for their cooperation. The Edinburgh Lead Study was financially supported by the Medical Research Council and the Scottish Home and Health Department. Views expressed in this paper are those of the authors and should not be attributed to either of the funding bodies.

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